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THE STATE UNIVERSITY OF NEW JERSEY

Morphology and genesis of long-tailed tropospheric tracer anomaly distributions

Benjamin R. Lintner[1*]

J. D. Neelin[2], Baijun Tian[3], Qinbin Li[2], Li Zhang[2], Prabir Patra[4], Mous Chahine[3], Sam Stechmann[5], Christopher E. Holloway[6]

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[1]Dept. of Environmental Sciences, Rutgers U.; [2]Dept. of Atmospheric & Oceanic Sciences, UCLA; [3]NASA Jet Propulsion Laboratory; [4]Frontier Research Center for Global Change (Japan); [5]Dept. of Mathematics, U. Wisconsin-Madison; [6]Dept. of Meteorology, U. Reading (UK)

[*]Note: My perspective here is as a data/model omnivore.

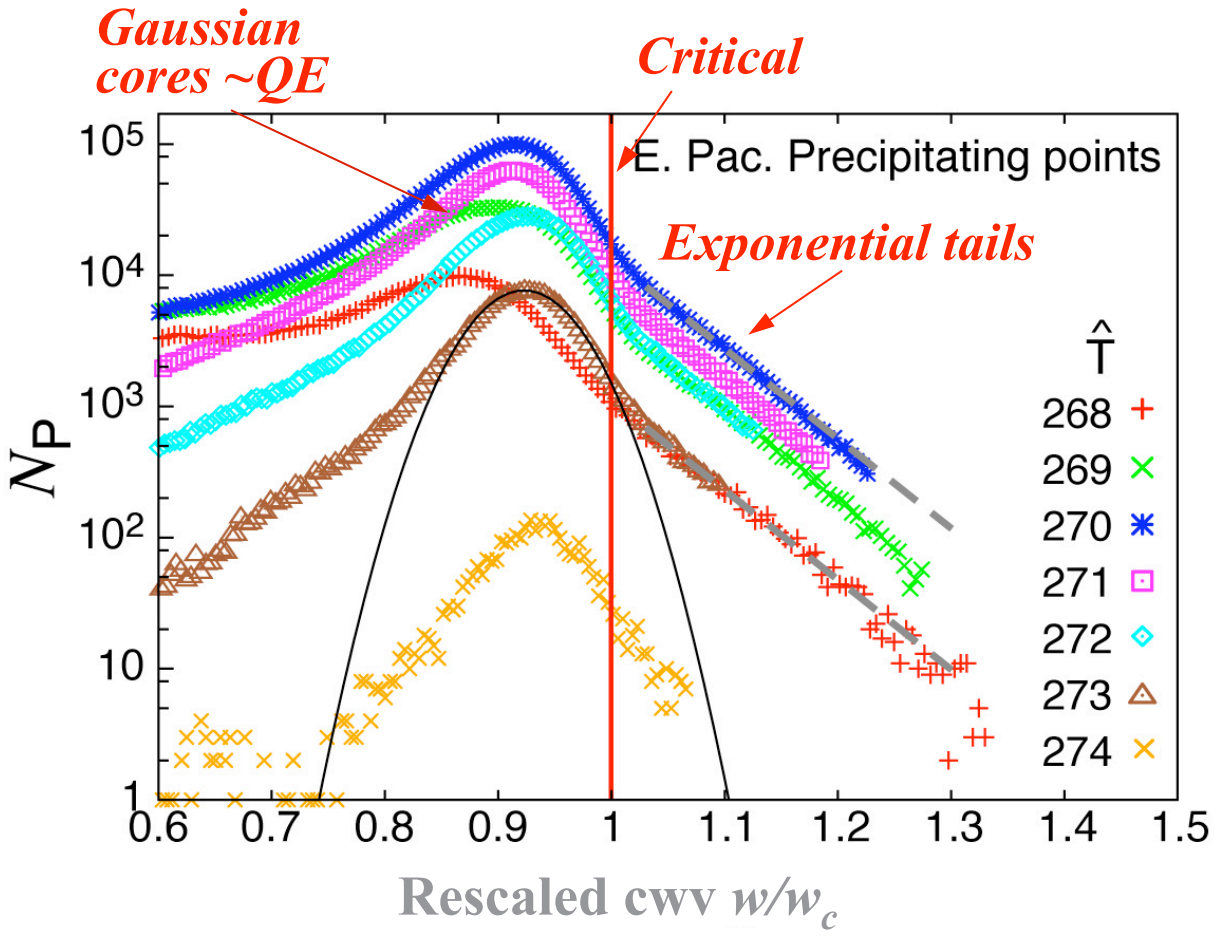
Overview

- Some background: Transition to strong convection; observations of column water vapor
- Tracer anomaly probability distribution functions (pdfs) for the tropics [Neelin et al., 2010]
  - *What?*: Daily departures from monthly-means for the entire tropics and regional subsamples of column water vapor (cwv) and other tracers
  - *Why?*: Present aspects of pdf morphology (e.g., "long tails") and establish ubiquity across a variety of tracers [including my one AIRS-related slide!]
- High frequency cwv anomaly pdfs @ Nauru in the western equatorial Pacific [Lintner et al., 2011]
  - *What?*: Subdaily-to-synoptic cwv anomalies
  - *Why?*: Explore genesis mechanisms for long-tailed pdfs
- Future directions:
  - Connections between convection, dynamics, and tracers
  - Multiple and/or idealized tracer approaches

Background: Transition to strong convection

- Convective quasi-equilibrium (QE) assumptions for convection parameterizations
  - Above an onset threshold [quantified in terms of, e.g., a critical column moisture value], deep convection (precipitation) increases in order to keep the system close to onset. [e.g., Arakawa & Schubert 1974; Betts & Miller 1986; Moorthi & Suarez 1992; Randall & Pan 1993; Zhang & McFarlane 1995; Emanuel 1993; Emanuel et al. 1994; Bretherton et al. 2004]
- There is a need for better characterization of the transition to deep convection as a function of buoyancy-related fields, i.e., temperature & moisture.
  - Both a temporal and spatial transition (e.g., yesterday's talk by Brian Medeiros)
  - Results from Peters & Neelin [2006], Neelin et al. [2008, 2009]: properties of continuous phase transition with critical phenomena

Observed frequency of normalized cwv counts



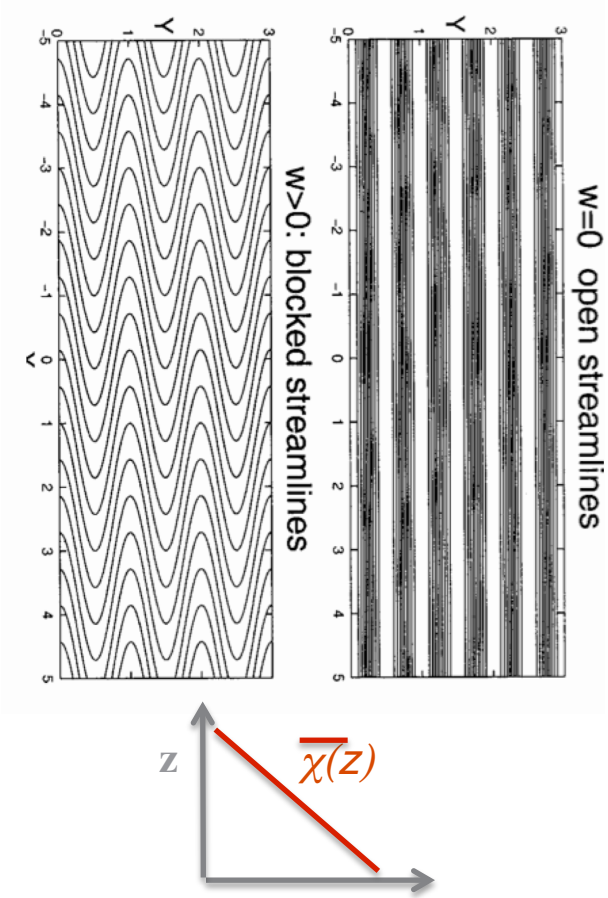
Neelin et al. [2009]

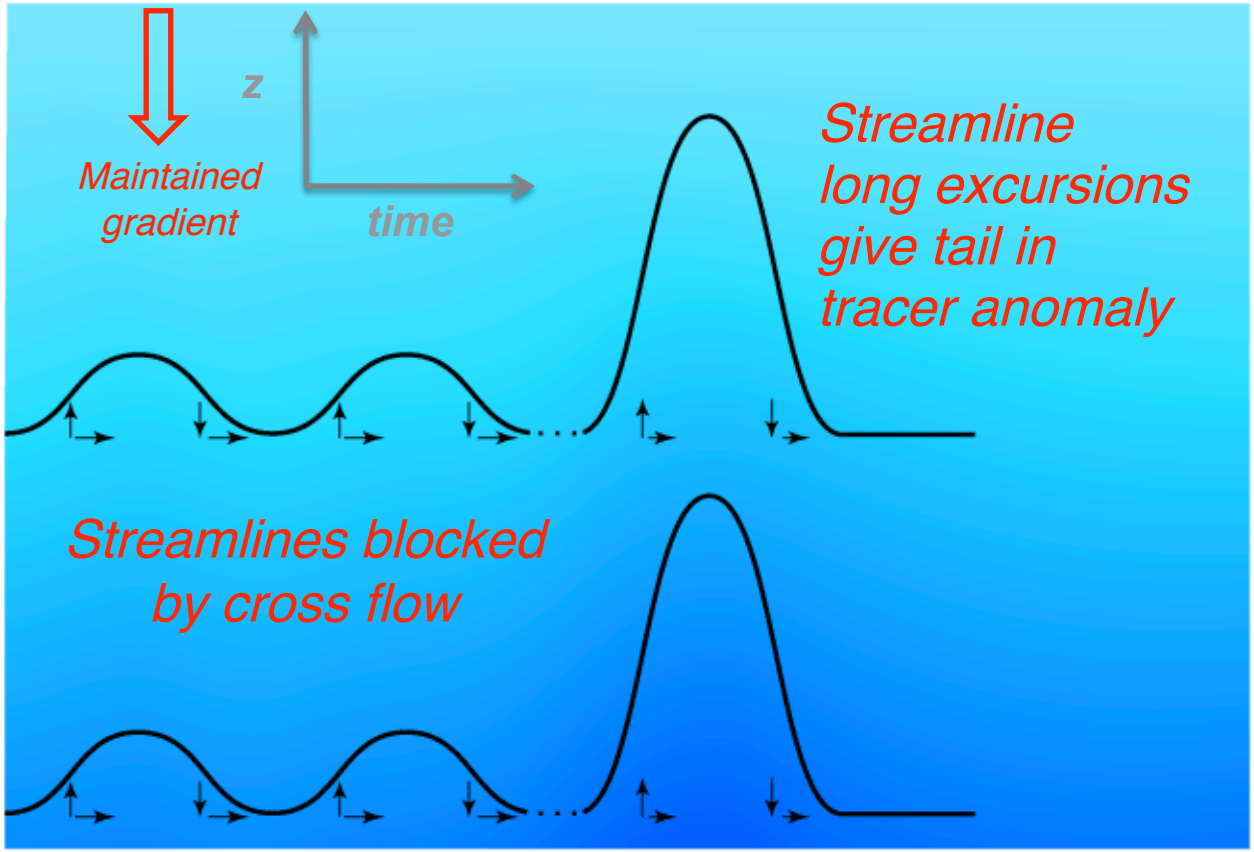
- Left: East Pacific region cwv (w) counts normalized by a ~vertically-averaged T-dependent critical cwv (w_c)
  - Gaussian cores slightly below critical and exponential tails above
- ***What accounts for such distributions?***

To be considered here:

- A straightforward mechanism for generating long tails in cwv pdfs [next slide] implies these should occur in other tropospheric tracers.
  - *Are long-tailed pdfs evident in satellite observations and chemical transport model simulations?*
- Note: While long-tailed stratospheric pdfs are known [Sparling & Bacmeister, 2000; Hu & Pierrehumbert, 2001, 2002], it's not obvious whether we should see them in vertical integrals of tropospheric tracers given the more complex flow in the troposphere.
  - Also: if similar tails are seen for other tropospheric tracers, then there is corroborating evidence that passive tracer mechanisms may be relevant to water vapor, even though water vapor is a highly active tracer.

Forced tracer advection-diffusion: a (simple) prototype for generating long-tailed pdfs*

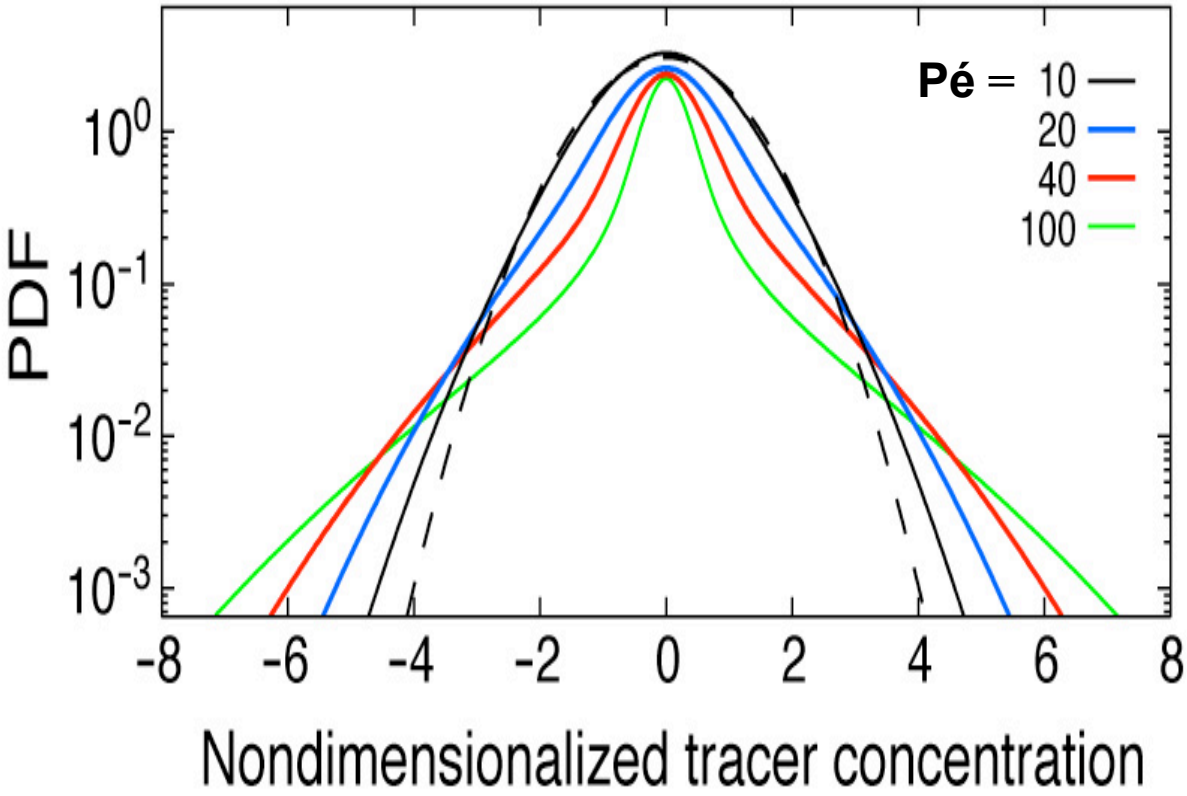




*Shraiman & Siggia [1994]; Pierrehumbert [2000]; Bourlioux & Majda [2002; BM02]

Passive tracer pdfs for idealized flows

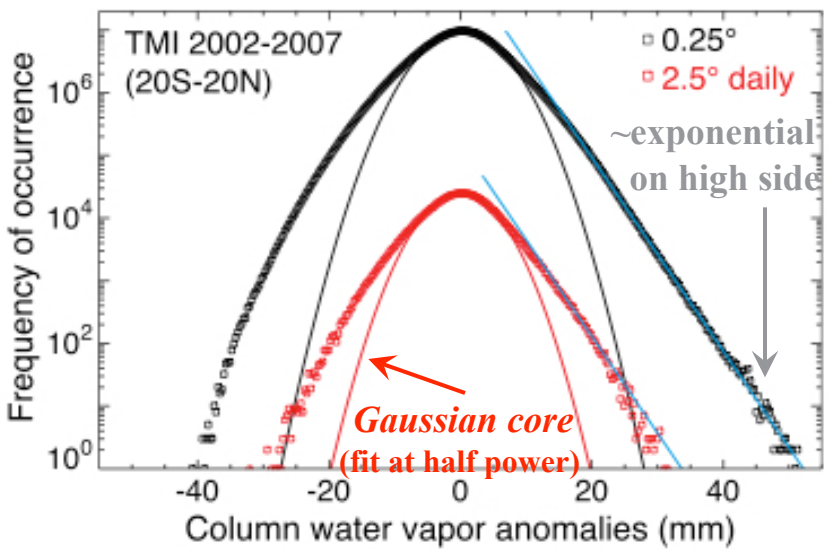
- 2D flow BM02 configuration:
  - "Vertical" cross-gradient flow is vertically uniform, horizontally sinusoidal, and stochastic (Gaussian) in time.
  - "Horizontal" along-gradient flow is is spatially invariant and sinusoidal in time.
- Right: Change in pdf morphology as Péclet number [Pé: the scale of advection/ diffusion ~ UL/ν] is varied.
  - Higher Pé corresponds to less Gaussian behavior across the normalized concentration range⇒longer tails

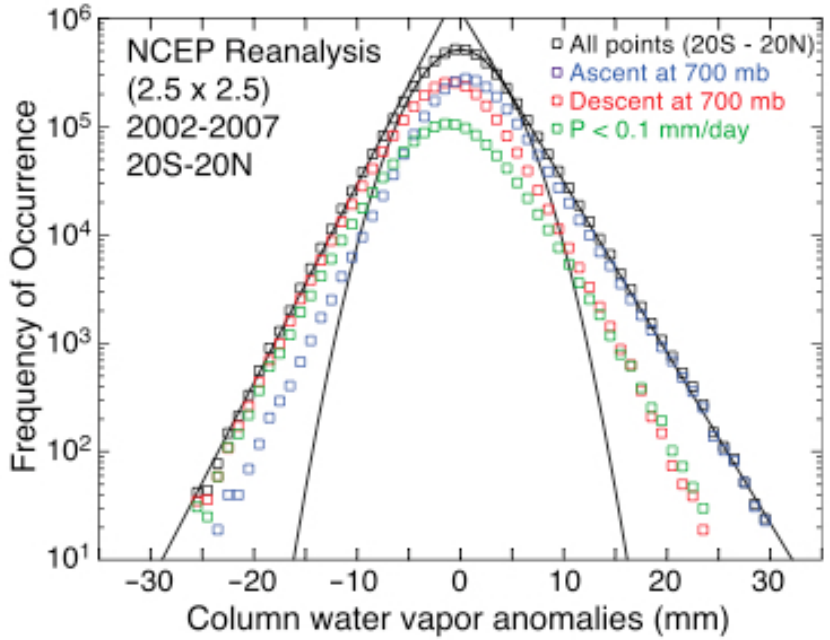


Neelin, J.D., B.R. Lintner, B. Tian, Q.B. Li, L. Zhang, P.K. Patra, M.T. Chahine, and S. N.Stechmann, 2010: Long tails in deep columns of natural and anthropogenic tracers. *GRL, 37*, L05804.

Tropicswide cwv pdfs

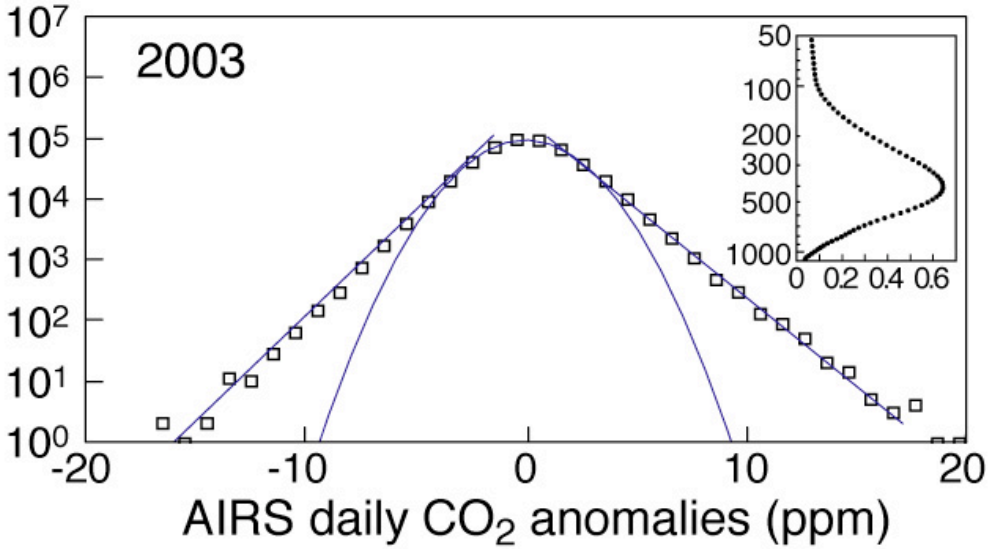
- Top: Tropical Microwave Imager (TMI):
  - Anomalies for instantaneous (scan resolution) and daily-means defined as departures from 30-day running means.
  - Gaussian cores [with fits to half max points] with *asymmetric* tails, i.e., approximately exponential or stretched exponential on the positive side.
- Bottom: NCEP/NCAR Reanalysis 1:
  - Positive/negative tails associated with ascent/descent in the lower free troposphere
  - For low precipitation conditions, the tails are still present, though more symmetric.
  - Processes associated with deep convection are not necessary for generating long-tailed cwv pdfs.

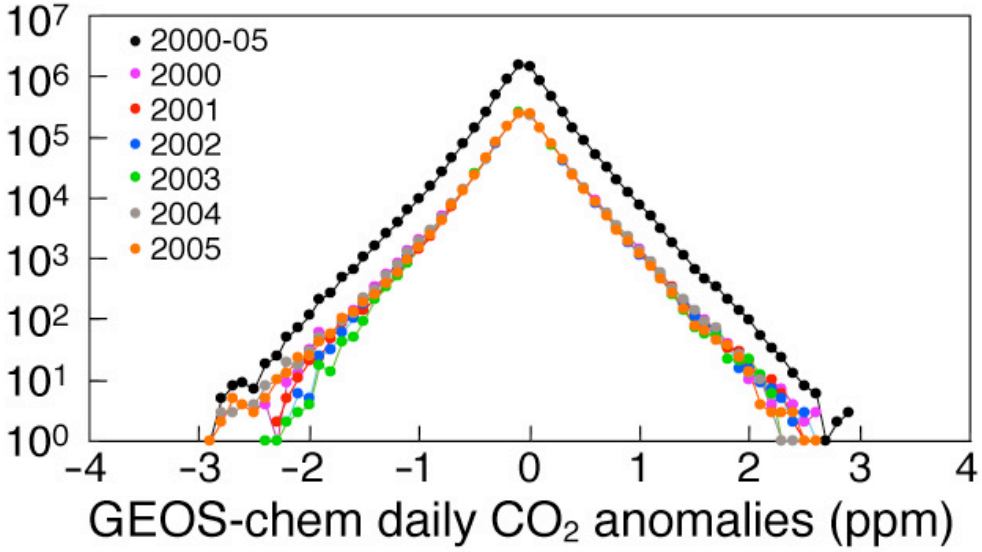




CO_2 pdfs

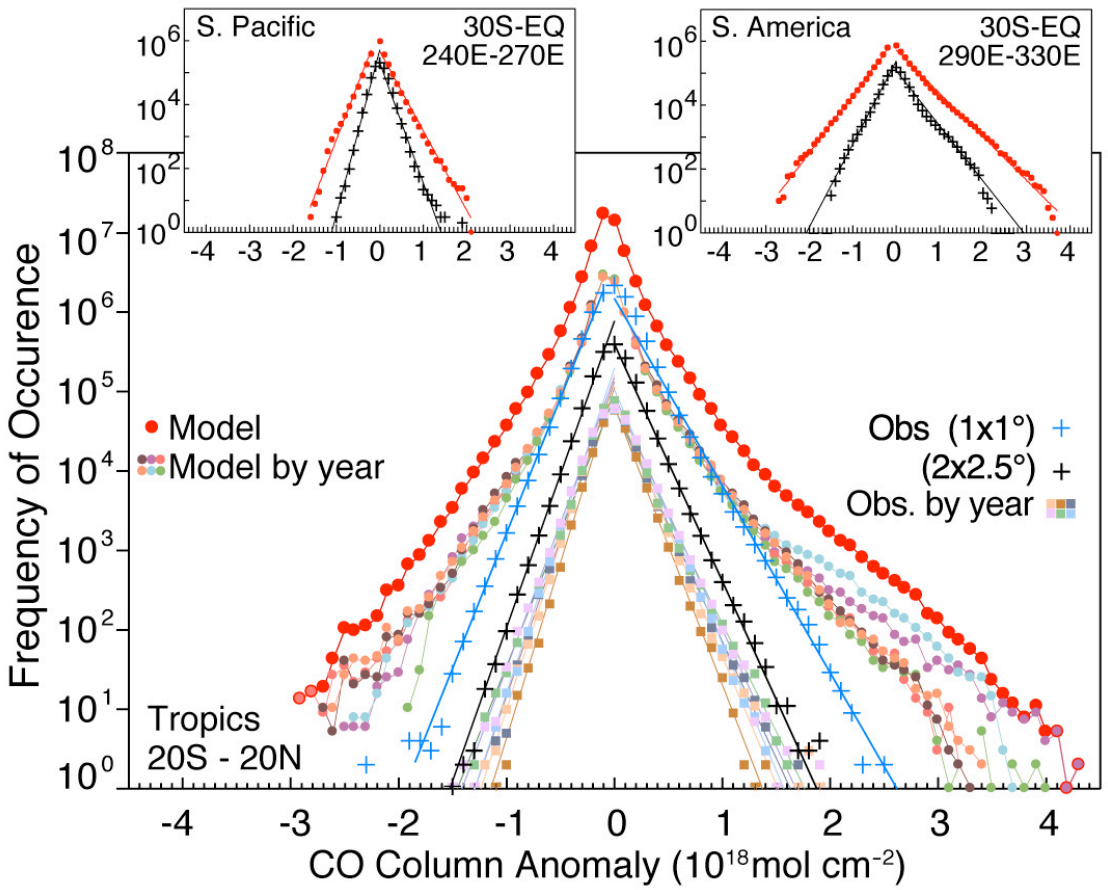
- Top: AIRS [Chahine et al. 2005, 2008] retrieval for 2003:
  - The retrieval's vertical averaging kernel is shown in upper right inset.
  - Daily anomalies from 30-day running means; 2.5º x 2.5º; 20ºS-20ºN
  - ~Exponential tails over 4 orders of magnitude
- Bottom: Multi-year GEOS-Chem simulated CO_2
  - Pressure-level CO2 is projected onto the AIRS kernel.
  - Distinct difference in the width of the simulated and observed pdfs ⇒ Known biases in vertical mixing in GEOS-Chem [?]
  - Year-to-year variations arise solely from transport, since the source/sinks of carbon are fixed.



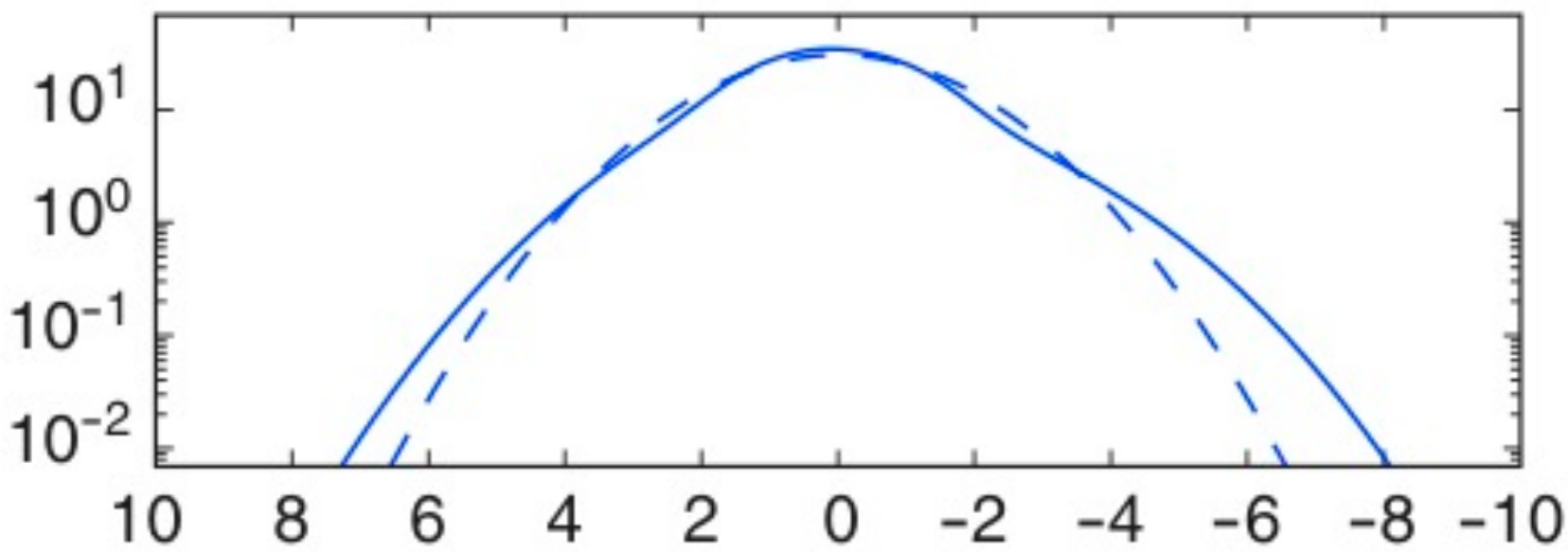


CO pdfs

- Measurements of Pollution in the Tropopshere retrievals (crosses/ squares) and GEOS-Chem simulations (circles)
  - Like CO_2, provides support for passive tracer advection/ diffusion generation of behavior in cwv.
  - But why such narrow cores?
- Insets: Regional observation-model intercomparisons
  - The two subregions are very different [oceanic, weakly convecting vs. land, strongly convecting]
  - That model captures relative change in width highlights how pdfs may be used diagnostically



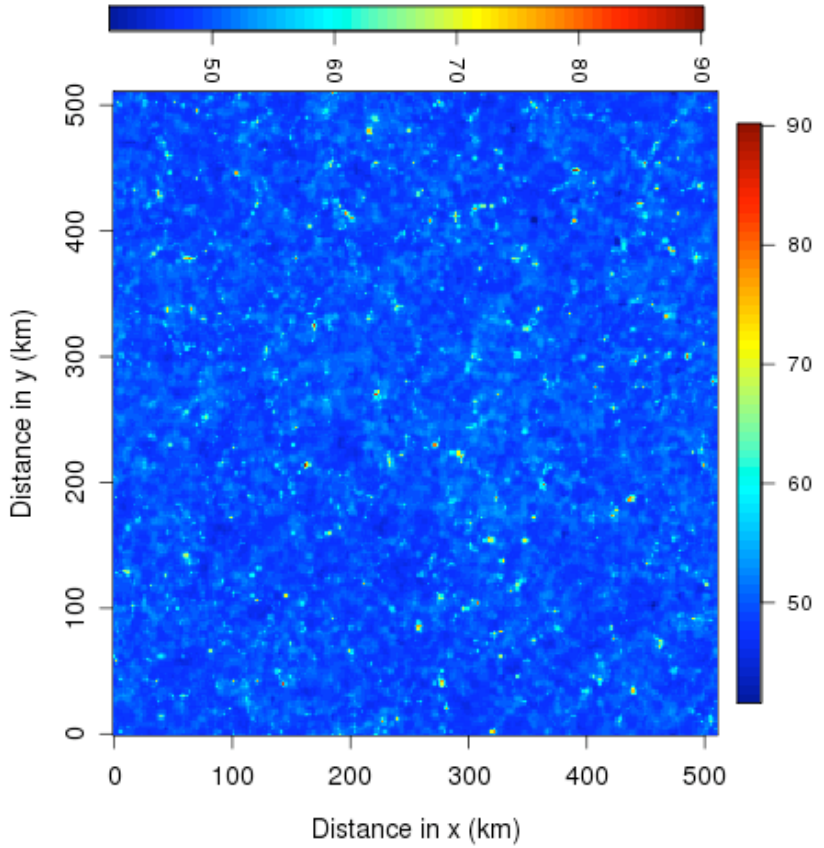
Explaining cwv tail asymmetry

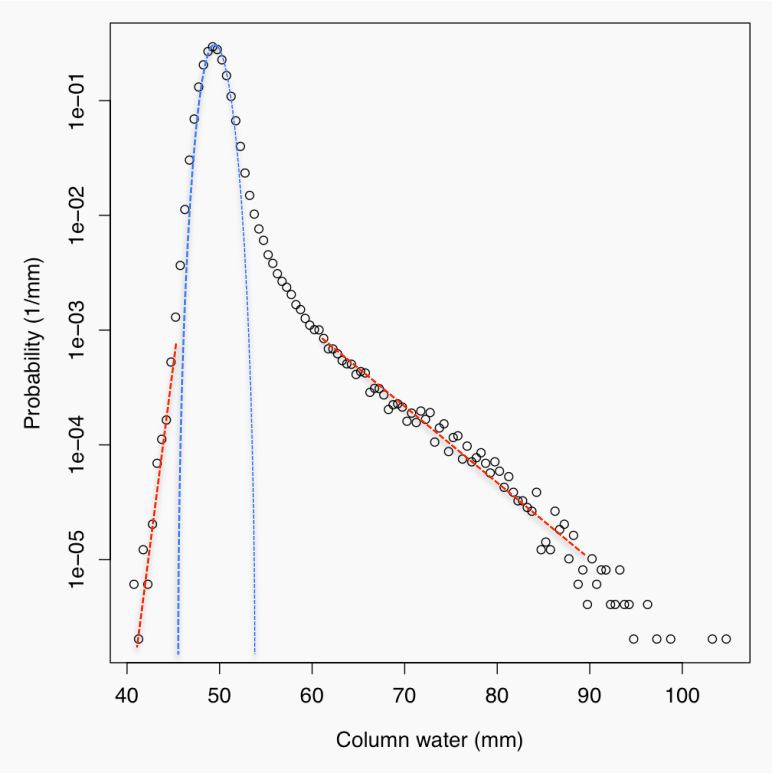


- Above: BM02 pdf modified through addition of a deterministic vertical velocity field
  - Stronger but less frequent upward motion, slower but more frequent downward motion [as observed and modeled (Hui Su's talk yesterday)] ⇒ Fatter positive side tail as in observed cwv
- *Other sources of asymmetry?*
  - Vertical structure/ behavior of moisture, i.e., nonuniform vertical gradient; BL "pinned" by surface coupling but FT can become very dry with persistent downward motion
  - Convective processes
- *How to tease these apart?*

cwv pdf from a cloud resolving model

Results courtesy of Dave Romps (UC Berkeley)

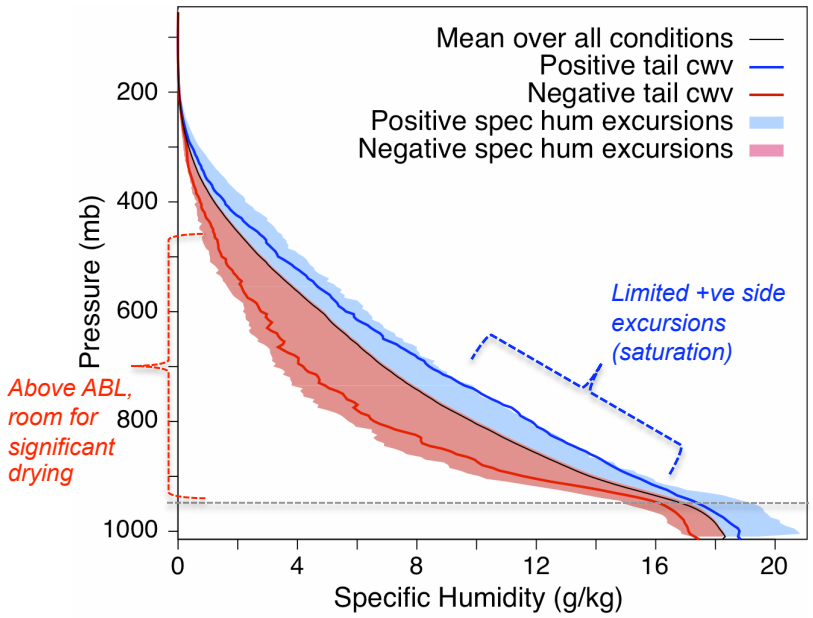


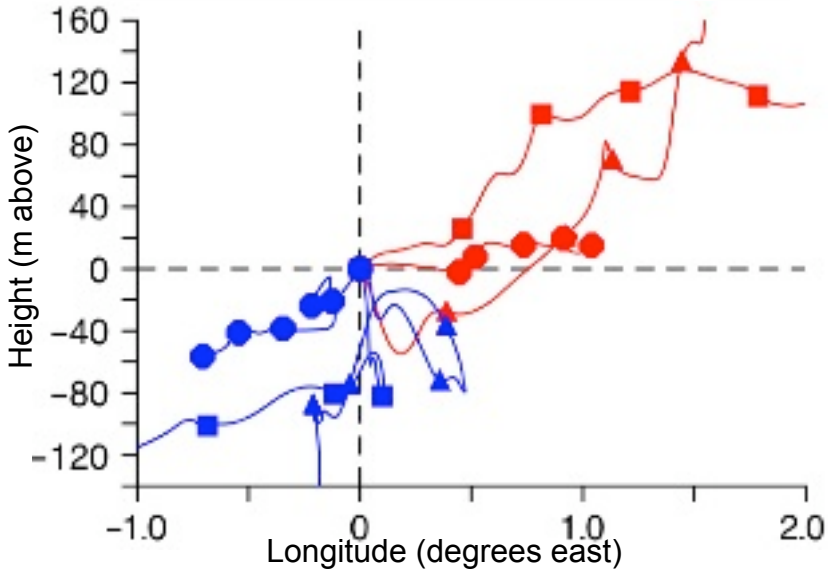


- Asymmetric long-tailed pdf for “plume scales”
  - No organizing large-scale vertical motion, but strong upward/downward asymmetry

High-frequency cwv pdfs @ Nauru (167°E, 0°N)

Vertical and horizontal structure of Nauru cwv





- Top: Mean sonde specific humidity profiles for ±2σ cwv anomalies
  - These illustrate what the pressure level q profiles look like considering "tail regime" cwv anomalies.
- Bottom: HYSPLIT 5-day backtrajectories in longitude/height for for ±2σ cwv anomalies
  - Descent/eastward (ascent/westward) origination associated with low (high) cwv at Nauru.
  - Thus, for this site, cooperative effects of flow across vertical and horizontal gradients associated with extreme cwv.

Lintner, B.R., C.E. Holloway, and J.D. Neelin, 2011: Column water vapor statistics and their relationship to deep convection and vertical and horizontal circulation and moisture structure at Nauru. *J. Clim, 24*, 5454—5466

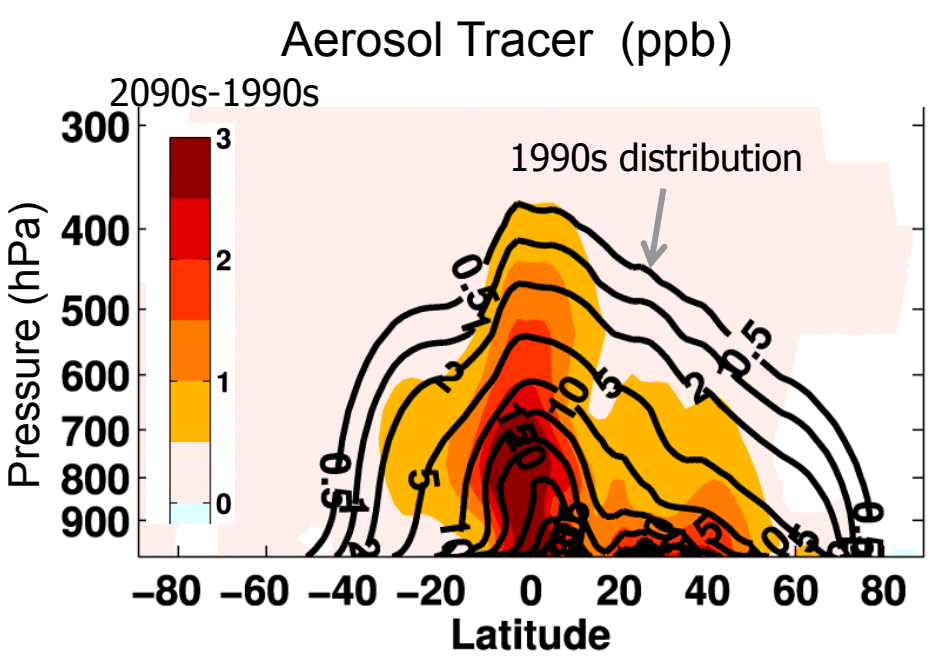
Summary

- The bulk pdfs for a variety of tracers, including water vapor, exhibit Gaussian cores and long (exponential or stretched exponential) tails.
- Idealized forced passive tracer advection-diffusion problem represent a simple prototype for understanding the genesis of such long-tailed pdfs.
- Diagnostics based on the properties of bulk pdfs, e.g., core widths, tail slopes, asymmetries, may be useful for analyzing models, particularly when large amounts of data are involved.
- Analogous results for cwv variability at higher frequencies for a single observing site (Nauru).

Future Directions: Changes in pollution extremes

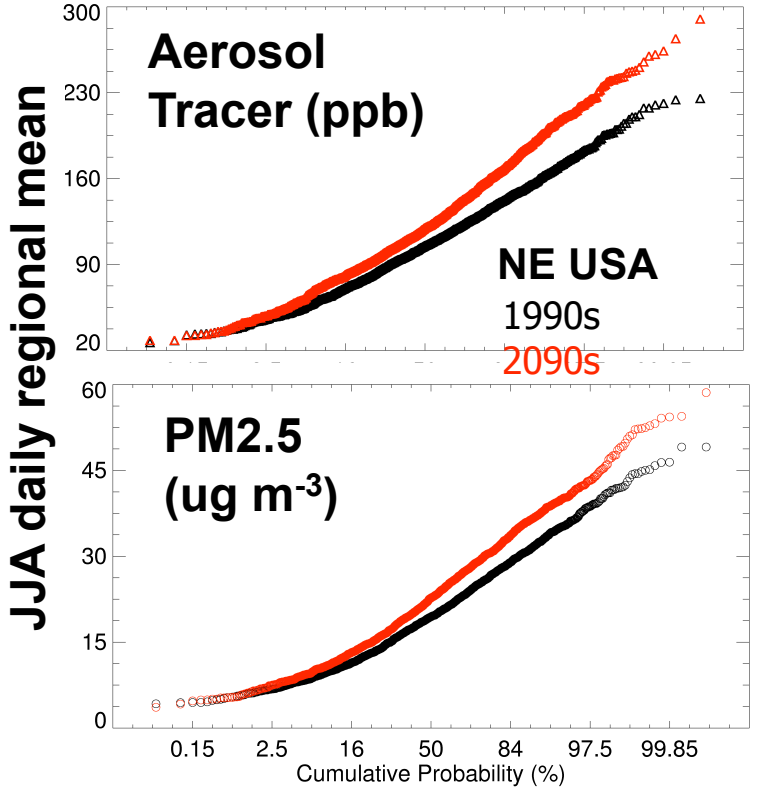
Results courtesy of Arlene Fiore (Columbia) and Yuanyuan Fang (Princeton)

Idealized GFDL AM3 climate change simulations (20 years)
1990s: obs. decadal-mean SST and sea ice; 2090s: 1990s + mean changes from 19 AR-4 models (A1B)
Aerosol tracer: fixed lifetime, deposits like sulfate (ONLY WET DEP CHANGES)



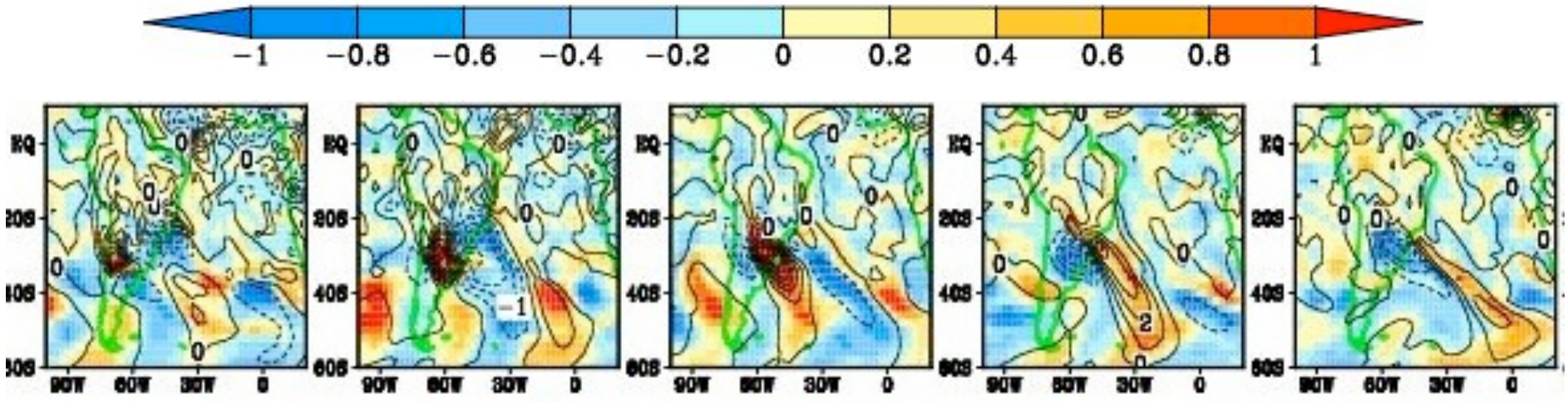
- **Tracer burden increases by 12% despite 6% increase in global precipitation**
  - Role for large-scale vs. convective precipitation
  - Seasonality of tracer burden

Y. Fang et al., 2011; Y. Fang et al., in prep



- Tracer roughly captures PM2.5 changes
- Cheaper option for AQ info from physical climate models (e.g., high res)

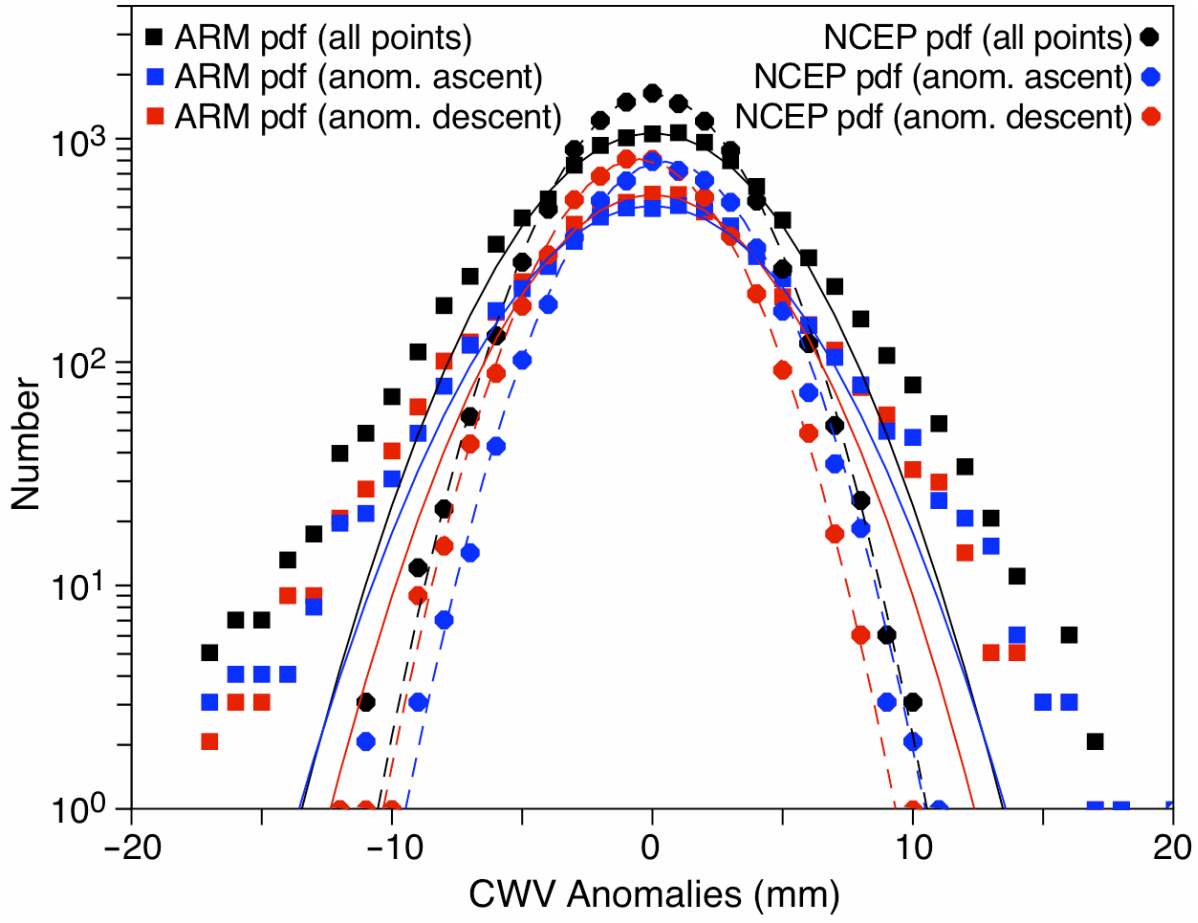
Future directions: Linking convection and tracers



- Above: GEOS-Chem cwv (shading) and CO (black line contours) for the period January 13th-17th, 2005 near the South Atlantic Convergence Zone (SACZ).
- The approach of a moist phase wave on the 13th (red shading) and subsequent eastward propagation is associated with a southeastward surge of high CO (solid lines). As this outflow moves into the Atlantic, it becomes sheared into a more filamentary structure that moves off toward higher latitudes.

- End

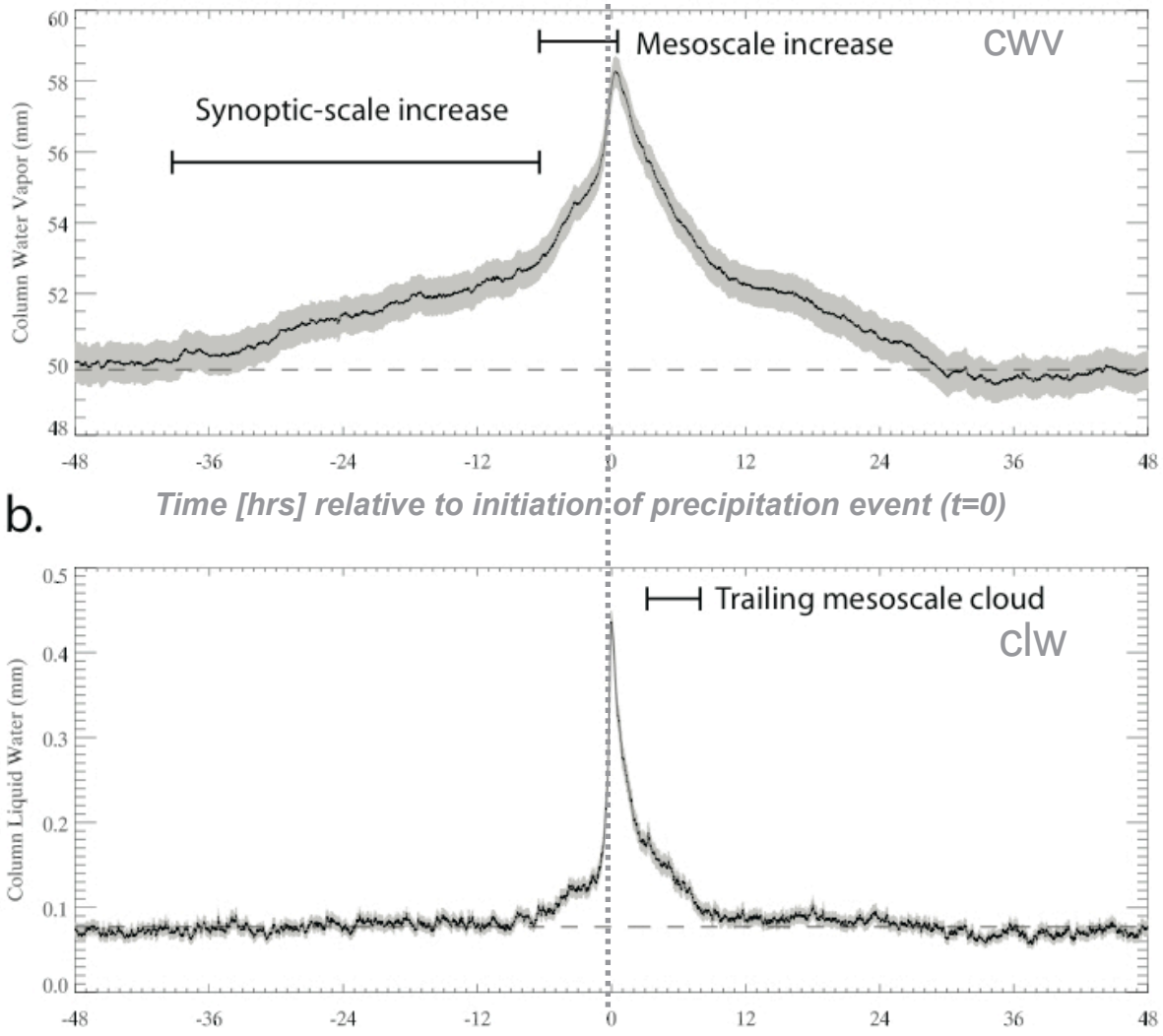
Comparison to NCEP/NCAR Reanalysis 1



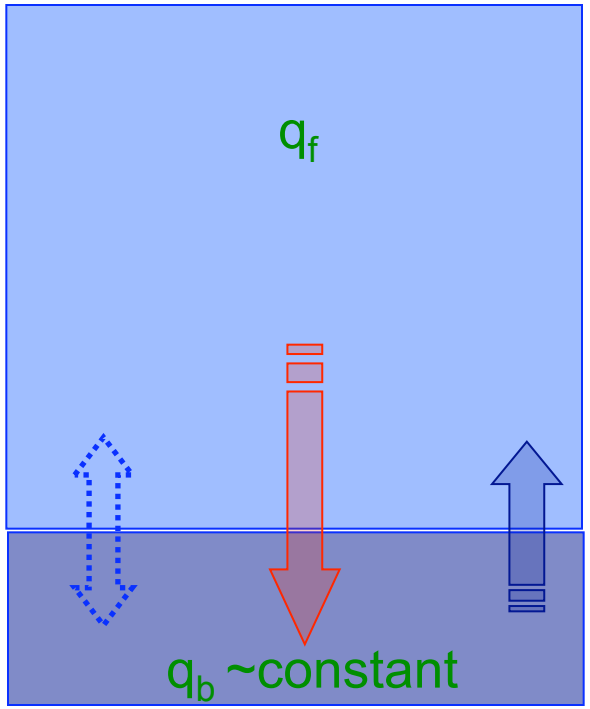
- 4 x daily reanalysis (circles) and ARM passive radiometer (squares) cwv:
  - Anomalies defined w.r.t. 5 day running means, with the radiometer cwv first aggregated to 6 hour averages.
  - pdfs are further conditioned on the reanalysis anomalous vertical velocity field
- NCEP pdfs are highly Gaussian
  - Not properly accounting for mesoscale circulation?

Lead-lag composites for Nauru cwv/clw and prec

Figure 7 from Holloway & Neelin [2010]



2 vertical level moisture model: shifting tails



$$\Delta p_t \frac{d\hat{q}}{dt} = -\omega q' - \theta(\hat{q} - \hat{q}_c)\Delta p_t \frac{\hat{q} - \hat{q}_c}{\tau_c} + \Delta p_f \frac{q_b - q_f}{\tau_m}$$

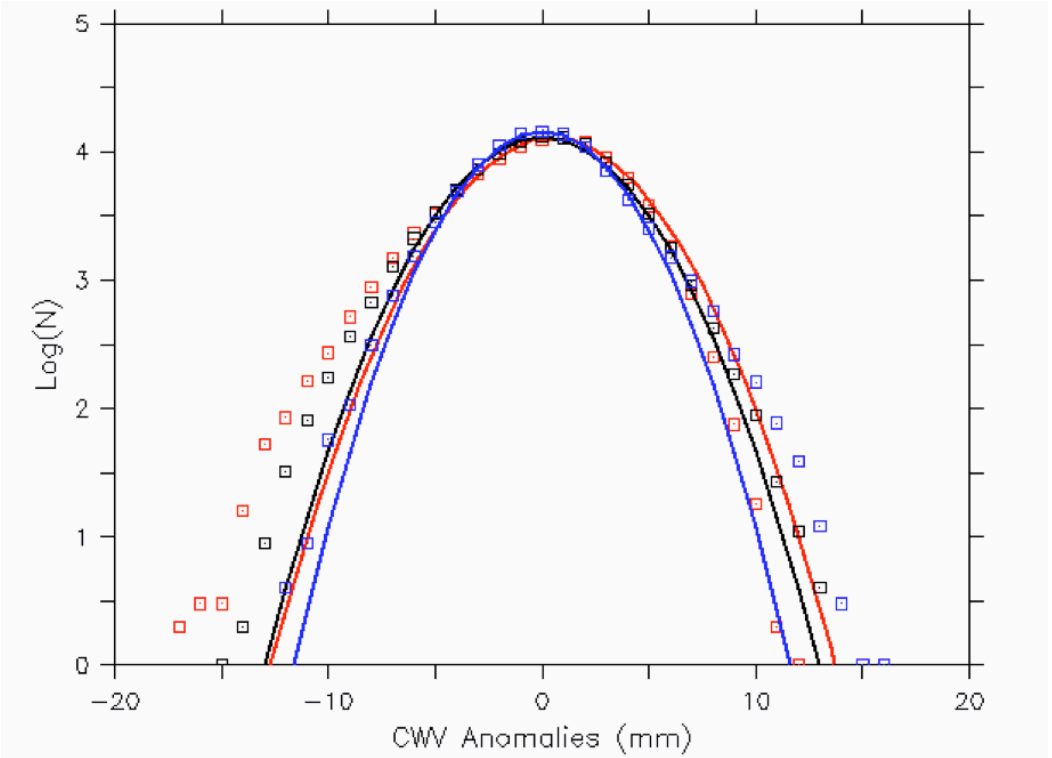


Fig. S1: Probability distribution functions (PDFs) of 2-level column water vapor anomalies computed with respect to different running-mean intervals: blue = 2 days; black =5 days; and red = 30 days. (Note that the values used are 6-hourly intervals; thus a 2 day running-mean is 8 intervals.)